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ABSTRACT

While little is known about the processes of creative cognition or about the structure of human memory, scholars do understand the immense task of unraveling the cortical structure and function of the human brain. Existing literature on creativity appears to obscure the processes of creativity far more than it clarifies the creative act. However, intrapersonal problem solving should be examined from a cognitive perspective. In pursuit of a theory of creativity based upon the principles of cognitive science, R. A. Finke, T. B. Ward, and S. M. Smith proposed a theoretical model that examined both the generative and exploratory cognitive structures used in creative cognition. Generative processes, "preinventive" structures and properties, and exploratory processes all combine in this "Geneplore" model, with attributes of the problem stimulus, to foster creative cognition. Creative cognition appears to require that both brain hemispheres be active during cognitive problem solving, which is not a problem since the cerebral cortex is organized around structures that support lateral cortical functions and "deep" neurological architectures. Brain modularity appears to contribute to the process of creative cognition in a number of ways. Creativity may also exist in the structures of the neurological pathways or the neurotransmitters that tie the operation of the brain together. Superimposing brain modularity, neurological pathways, and neurotransmitters on the Geneplore approach to creative cognition would result in a complex model worthy of the complexity of the creative act itself. (Two tables and one figure presenting aspects of the Geneplore model are included. Contains 24 references. (RS)

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CREATIVITY AND CONSCIOUSNESS IN PROBLEM SOLVING: CREATIVE COGNITION AND THE MODULAR MIND.

by

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Creativity is a difficult subject to investigate. Most of the evidence that has been gathered and the explorations that have been conducted in the areas of imagination, creativity, insight, discovery, and problem solving, have been either introspective or anecdotal in nature. Many of the artists, historians and scholars who have examined the creative act, have described the process of creativity as a mystical *force majeure* or with the kind of circular reasoning --- highly creative people think in highly creative ways, and thus do highly creative things --- that dismisses the possibility that cognitive phenomena can be broken down into component processes.

On the other hand, efforts to study creativity in some type of controlled setting, are often met with contempt and outrage: How can *science* attempt to quantify an act that is so spontaneous and unpredictable that it defies examination or explanation? We are frequently reminded by these critics that any attempt to measure creativity would, in essence, destroy the creative process itself.

Undaunted by these pitfalls and criticisms, this paper intrepidly examines intrapersonal problem solving from a cognitive perspective, and offers some observations concerning the potential relationship between creative cognition and neurophysiological structures of human brain.

Studying Creativity

Books and articles on creativity are often enigmatic. Purporting to help us analyze what creativity is and how it occurs, these books fall into three major categories: case studies, pragmatic texts, and scholarly investigations.

Case studies are either interviews with creative artists and scientists (Gardner, 1982), or the analyses of the individual acts of creative people, as revealed through an examination of their diaries, logs, and notes (Gruber & Barrett, 1974; Holoman, 1979). Introspective reports, that examine the creative process, are frequently symposia in which many of the greatest minds of our time seek to describe their own creative processes and accomplishments (Ghiselin, 1952) , or biographical studies that either define the lives of creative artists and scientists, or describe the accomplishments of brilliant people (Wallace and Gruber, 1989). These exemplars of "creative genius" are notoriously vague, unfulfilling, and untrustworthy approaches to furthering our

practical knowledge about creativity. In part, this is due to the inaccessibility of the creative phenomena for formal observation, the inability of individuals to fully comprehend their creative cognitions, and the inadequacy of language to express these internal thought processes.

Pragmatic approaches to creativity focus primarily on innovative applications of creativity and the development of problem solving techniques. These normally take the form of self-help books and articles which attempt to provide useful strategies to individuals who want to "enhance" their creative efforts, or expand their creative abilities. Frequently these books and articles are published as exercises that readers may practice, or puzzles that individuals can solve, in order to sharpen their creative skills. With titles like "Drawing the light from within: keys to awakening your creative power" (Cornell, 1990), "Mavericks: Lead your staff like Einstein, create like Da Vinci, & invent like Edison" (Blohowiak, 1992), and "Thinkertoys: A handbook of creativity in business" (Michalko, 1991), these efforts fail to assist people in understanding the component processes of creativity, and in applying creative strategies under diverse sets of conditions and constraints.

Scholarly investigations of creativity often fare no better. Research articles and doctoral dissertations on the subject of creativity often deal with the narrow conceptualization and measurement of creativity that address only a small dimension of the complex creative process. Attempts to develop formal theories of creativity have normally applied the case study approach. Psychoanalytic investigations of creativity (Koestler, 1964) have suggested that the creative act emerges primarily as a resolution of unconscious conflicts, as dissimilar and disassociated subconscious patterns are merged together. A contrary psychoanalytic theory (Rothenberg, 1990) rejects the notion that creativity is grounded in neurosis, and views creativity as a "healthy" preconscious process that helps the individual as a coping mechanism for stressful situations.

Attempts to operationalize creativity through psychometric approaches (Guilford, 1950; Brightman, 1980; Hayes, 1989) have resulted in the identification of cognitive traits or styles that are associated with creativity. Further extending this approach are biofeedback techniques in creativity (Cade & Coxhead, 1979) that attempt to enhance creative problem solving. The benefit of these approaches lies in their identification with a variety of component processes required for creative problem solving, as opposed to unidimensional constructs that attempt to define creativity. Finally, sociological approaches

(Amabile, 1983; Simonton, 1990) concern themselves with the cultural and environmental factors which affect creativity, or the social conditions under which creativity flourishes.

These books and articles appear to obscure the processes of creativity far more than they clarify the creative act. After reading this literature the reader is, at worst, confused by the circularity of many of these arguments. At best, the reader is more inspired than enlightened regarding the creative process. And although some scholars have examined a number of isolated cognitive strategies involved with creativity (Brightman, 1980; Amabile, 1983), these studies normally avoid: an analysis of the complex cognitive processes that those strategies would entail, the specific cognitive phenomena underlying the creative performance, and the characteristics of the resulting cognitions that would distinguish them as creative. Creativity is one of the most important cognitive processes in which we engage, and one of the most complex capacities that we, as humans, have been genetically endowed to employ. But there is far too little that can be learned about the cognitive phenomena of creativity and its component processes by reading most of these publications. A new approach is clearly warranted

A Creative and Cognitive Challenge

Scholars and authors who have written about creativity have frequently avoided the complex issue of cognition, where the intention would have been to analyze the various cognitive processes that could stimulate different creative strategies across different cognitive domains. Primarily, because they were trying to create simplistic and unidimensional understandings of what appeared to be complex and hierarchical processes, these writers avoided generating the specific, multiple, and essential cognitive principles that are the foundation of creative processes: across different schemas, across different problem structures and contexts, across different task requirements, and even across different dimensions of cognitive physiology.

These principles of creative cognition should be operationally defined so that problem solving in one domain can be applied to another domain, as long as the principles are broad enough, and the strategies are flexible enough to incorporate changes in problem structures and creative situations. At this point, a taxonomy of the specific and underlying cognitive operations that generate

and manipulate creative processes could be developed. A second challenge is in conducting these investigations within the framework of existing terminology and common language, rather than creating new words and phrases to provide insight into novel areas, and claim these observations and investigations as the authors' own.

The pragmatic approach to this process would be to limit any investigation to the conscious forms of creative cognition. Although preconscious cognition (Marcel, 1983; Reber, 1989) probably occurs in all forms of problem solving, such as insight, intuition and incubation, it would be extremely difficult to attempt to operationalize and quantify these processes at this time.

Toward a Theory of Creative Cognition

Creativity is not a simple and unified process, but rather a complex product of multiple cognitive structures built upon preexisting neurological capacities from an infinite inventory of possibilities. Cognitive structures, although often undetected in the product of creative thinking, combine to set the stage for creative insight and discovery, and form the basis for exploring the origin of creative ideas.

The Geneplore Model

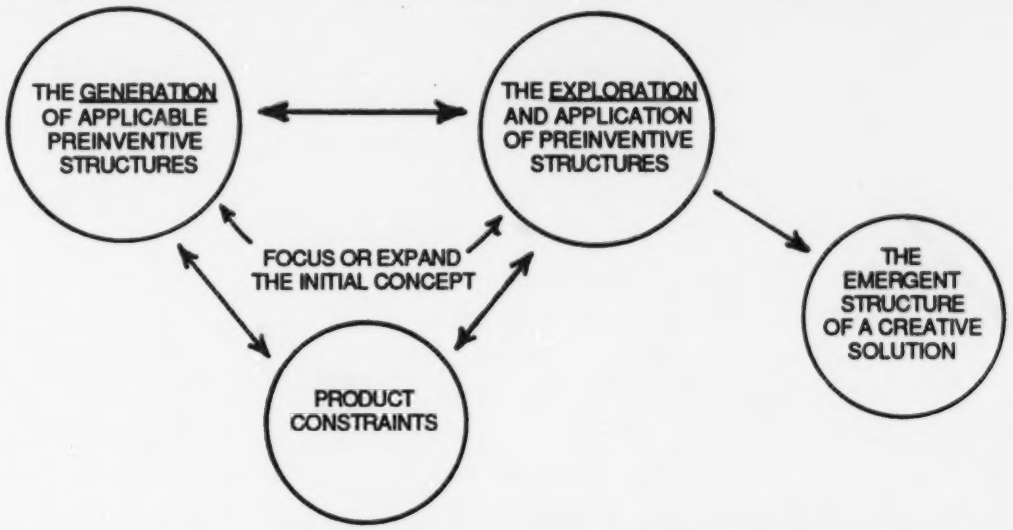
In the pursuit of a theory of creativity based upon the principles of cognitive science, Finke, Ward, & Smith (1992) proposed a theoretical model that examined both the generative and exploratory cognitive structures used in creative cognition. The Geneplore model consists of two separate phases. The first stage is the generation of key mental representations, called *"preinventive structures"* (p. 17), which focus on key properties extrapolated from the structure of the problem.

Generative Processes

Preinventive structures may be thought of as cognitive strategies for investigating problems, or tools that one could use to discover novel application for creativity within the constraints of the task. In terms of insight, preinventive structures are the methods one uses to develop or acknowledge new perspectives that can be then compared to known structures or functions that are under analysis. Preinventive structures are based upon the cognitive schema that individuals adopt for problem solving. As they expand into their problem solving capacities, individuals expand their "problem framing" schemata, and develop a

repertoire of *property analyzing structures* based upon the the task at hand, and their past experiences with similar problems. These preinventive properties promote creative analysis and may be revealed through the use of *analogues, metaphors, mental transformations* or a variety of cognitive strategies (see Figure 1). In the second stage, these properties are then manipulated during *exploratory* efforts, as the individual seeks to give these preinventive structures meaningful applications.

Figure 1
Finke, Ward, & Smith's Geneplore Model of Creative Cognition.


THE GENERATION OF APPLICABLE PREINVENTIVE STRUCTURES
THE EXPLORATION AND APPLICATION OF PREINVENTIVE STRUCTURES
FOCUS OR EXPAND THE INITIAL CONCEPT
THE EMERGENT STRUCTURE OF A CREATIVE SOLUTION
PRODUCT CONSTRAINTS

If these initial preinventive structures are useful in developing solutions to the task at hand, they may be filed away for future reference, or they become a dominant part of the individual's problem solving schemata. If they are not successful, the individual can propose alternate strategies by returning to the generative phase of identifying new preinventive structures until he/she hits upon an an *emergent structure* that appears to satisfy the task at hand. These emergent structures are then explored, in terms of their problem directed or product directed properties, until they are restructured, or a until a creative solution or product is finally conceptualized.

Thus, Finke et. al. have indicated that the foundation of creative cognition is the reflexive activity that takes place between its processing components: the generative phase and the explorative phase of preinventive structures. The

order in which this process takes place, or the number of refinements that a mental representation goes through, is not as important as the two-step process that occurs here (Katz, 1978). Among these generative processes identified by Finke et. al. (1991) are *memory retrieval, association, mental synthesis, mental transformation, analogic transfer, and categorical reduction* (p. 20-21). An extensive body of cognitive literature already exists in these areas identified as components of the generative process. Therefore they will be briefly addressed here.

Retrieving existing structures from memory, and the creation of *associations* among these mental structures, are two of the most accessible and successful generative processes (ibid pp. 58-61). Typically this is how rapid problem solving comes to us. On the other hand, *mental synthesis*, requires more concentration on specific component parts of a problem stimulus, than do retrieval or association. In mental synthesis the component parts are manipulated into new shapes or arrangements, resulting in *mental transformations* of the original forms (ibid pp. 53-55). *Analogic transfer* occurs when a set of characteristics in one context are translated into a second context and applied to the problem stimulus. Analogies are very successful ways of generating new categories of responses in problem solving (ibid, pp. 176-178). *Categorical reduction* is the process of simplifying objects, images, or events, until the most simplistic categorical descriptions remain. This is a process whereby the essential properties or fundamental applications of the problem stimulus are distilled from the original form (ibid, pp. 179-180).

Exploratory Processes

The exploratory processes are attribute finding, conceptual interpretation, functional interference, contextual shifting, hypothesis testing, and searching for limitations (ibid, pp. 24-26). Stated in another way, preinventive structures are *processes* that one applies to the goal, which is the *product* of the creative act. If the generative phase is finding the processes, the exploratory phase is exploring and interpreting those preinventive implications. By continuing, modifying and regenerating these processes the individual would eventually identify the emergent structure of a conclusion or solution. Once that conclusion was deter-mined, a different set of mental representations can be generated through different types of mental processes, to explore or critique the applicability of former conclusions.

The generative and exploratory structures that are catalogued below are representative of generative and exploratory preinventive structures, and are not meant to be exhaustive (see Table 1).

Table 1
Finke, Ward, & Smith's Generative and Exploratory Phases of Creative Cognition.

Generative processes	Exploratory processes
memory retrieval	attribute finding
association	concept interpretation
mental synthesis	functional inference
mental transformation	contextual shifting
analogic transfer	hypothesis testing
categorical reduction	searching for limitations.

All these components may be exchanged back and forth, individually or in pairs. Thus, for example, a mental representation could be *retrieved from memory* and *associated* with an aspect of the target problem. This mental representation could then be explored for *similar attributes* between the generated representation and perceived components of the target problem. If that procedure was unsuccessful, the initial mental representation might have to be *transformed* to fit a new *conceptual interpretation* of the problem attributes or constraints. This flexible process allows for the probability that people will be creative in completely different ways.

Exploratory processes are the methods through which we apply the forms that have been generated. *Attribute finding* is the search for and confirming the properties, attributes or features that were part of the preinventive structure (ibid, p. 49). *Conceptual interpretation* is the process by which we interpret the features of preinventive structures and apply them to novel conceptual domains. Conceptual interpretation is used successfully in the systems approach to problem solving (ibid, pp. 98-104). *Functional inference* refers to the use of the preinventive structure in some formal way (ibid, pp. 86-87). An example of functional inference occurs when you happen upon an odd shaped tool or kitchen gadget that you have no idea what it is for. The process of applying its "preinventive structure" to a useful purpose is how functional inference can be applied. If you take that same unknown gadget and try and think of it's application in a whole new setting, *contextual shifting* has occurred (ibid, pp. 165-166). If you use the problem stimulus as a solution to a particular problem,

you are probably *hypothesis testing*, but if you are exploring why a particular preinventive structure will not succeed in a particular application, you are *searching for limitations* (ibid p. 187).

However, the Geneplore model becomes more realistic and more dynamic by adding preinventive structures and preinventive properties between the generative and exploratory phases of the model (see Table 2).

Table 2
Cognitive processes, structures, properties and constraints in Finke, Ward, & Smith's Geneplore Model of Cognitive Creative Processes (p. 20).

Generative Processes	Preinventive Structures	Preinventive Properties	Exploratory Processes
Retrieval	Visual patterns	Novelty	Attribute finding
Association interpretation	Object forms	Ambiguity	Conceptual
Synthesis experience	Mental blends	Meaningfulness	Functional
Transformation shifting	Category exemplars	Emergence	Contextual
Analogical testing Transfer	Mental models	Incongruity	Hypothesis
Categorical reduction	Verbal combinations	Divergence	Searching for limitations

Preinventive Structures

In the second column of Table 2, preinventive structures include *visual* and *spatial images* (patterns forms, pattern recognition, and pattern exploration). Many of the corporate logos that are designed for corporate identity begin as mental images that are rotated, bisected, superimposed, or combined with other images, and transformed into a new entity. These visual and spatial images are an exploration into creative visual synthesis.

A third type of structure is what Finke et. al. refer to as a *mental blend*, or the use of conceptual combinations, metaphors, and mental images. The notion here is that two distinct entities have been combined together to create a third conceptual category. Free visual association allows an individual to combine various independent shapes (such as letters or concrete symbols) into new shapes that have a meaning separate from those of its component parts (p. 22).

Category exemplars are a fourth type of preinventive structure. These are the generation of "unusual or hypothetical categories" (Ibid, p.22) from known or existing categorical structures (how many uses can the subject for a common object like a paving brick). These types of creative tasks require the individual to assess the properties of the object or concept, and use them as preinventive structures for further application. In an attempt to generate a new flavor of ice cream, one might begin with imagining "ice cream like qualities" (cold, solid, sweet particles suspended in frozen fluid, a cold, confection that encourages indulgence) that in some cases will closely resemble the original stimulus, and in other cases will not.

Mental models are more complex preinventive structures. While schemas are important frameworks for structuring cognition (schemas often assist in the structuring of new data toward internal information, and inferences based upon that information), mental models are more flexible and require conscious imagination to complete. Novel scenes in a movie, events, societies and even entire new worlds require complex imagination to complete (Ibid, p 22).

Verbal combinations are disassociated words that are paired together to suggest interesting or novel relationships that can lead to poetic references or analogic explorations. In what ways are a human hand and the sail from a boat similar? What would constitute the "sail's *hand*"? Would this be the tiller of a boat? What would be the "hand's *sail*"? What physical, visual, or conceptual properties do these terms share? Can these two terms be combined to generate a creative verbal analogy? (Ibid, p 22-23).

Preinventive properties

Preinventive properties are characteristics of preinventive structures that vary according to the problem stimulus and the creative insights that are aroused. Finke, et. al. indicate that preinventive properties foster different mental relationships, which in turn stimulate different creative outcomes.

Novelty, as a preinventive property, is certainly a key factor in exploration and discovery. Although common structures can be interpreted in novel ways, it is often helpful in creative cognition if the structure of the problem stimulus was novel rather than common. There seems to be a certain "mind set" at work with recognizable concepts or shapes that limits the generation of creative insights. When novelty is a property of the preinventive structure, creativity seems to flourish (Ibid, p 23).

Ambiguity in the structure of the problem stimulus, tends to expand creative interpretations or possibilities, and further lends itself to creative exploration. *Implicit meaningfulness* is the implied meaning in a structure that the individual perceives. This "sense of meaning" (Ibid, p 23) in the structure of the problem stimulus is a potential for developing new and unanticipated meanings, thus furthering exploration and interpretation. If the implicit meaningfulness is high, creativity seems to be stifled. If the implicit meaningfulness is low, underlying structures, or hidden meanings for the preinventive structures may surface and increase the creative discovery.

Emergence is the extent to which unpredicted features or unexpected relations can occur in the preinventive structure. Two existing forms can be synthesized to create a new form. Emergence is the discovery in the reinventive structure of unexpected characteristics. Emergence can also be revealed by inclusion (none of these pieces seem to fit together...how are they similar?) or exclusion (only one part of the puzzle doesn't fit..how is it different?). *Incongruity* is the contrast between dissimilar properties in the preinventive structure. This observation often encourages deeper analysis and exploration of those specific contrasts to avoid the conflict between them. *Divergence* is the property of "plasticity" in the preinventive structure. This is the capacity for defining multiple meanings in, or uses for, the same structure (Ibid, p 23-24). How these preinventive properties relate to one another, and to other features of the preinventive structures, has a great deal to do with the number of emergent structures that result from the problem stimulus.

The types of cognitive processes and structures that have been examined here, detail the variety and complexity of the creative process. Generative processes, preinventive structures and properties, and exploratory processes, all combine in highly ingenious ways, with attributes of the problem stimulus, to foster creative cognition. The advantage of this pattern of creative cognition is that it accounts for many of the findings in creative cognition experiments, and suggests new ways to generate further studies. But of greatest importance, this model of creative cognition addresses the different types of cognitive functions that rely upon many highly differentiated mental processes that constitute the act of creative thinking. The act of mentally exploring the structures of creativity, and discovering their meaning, may be more complicated than the creative act itself.

The Physiology of Creative Cognition

The Geneplore model of creativity (Finke et. al., 1992) provides a compelling and (at times), an ingenious approach to creative cognition. Yet, it is but only one example of a theoretical framework for thinking about creative cognition. There may be more complete or better models to extend research efforts in creative cognition. However, a second important set of issues is raised by this theory. If the generative and explorative model of creativity accurately represents the dual phases of the creative process, then where in the psychophysiology of cortical functioning do these extensive processes occur? Where does creativity reside, or more accurately, what cortical structures interconnect to enable the creative process to occur? Indeed, these are persistent questions which have yet to be adequately answered by any formal theory of creativity, or by any cognitive model of the creative process.

In approaching these issues, it seems clear that selective adaptation would have favored the development of emergent, neurophysiological structures for human creativity (Gazzaniga, 1992). *Just as the brain shaped human creativity, human creativity also shaped the brain.* This physiological and cultural relationship cannot be overlooked. If indeed our species can be identified by our ability to abstract, plan, and think creatively, then inherent structures in the brain must have developed to enable creative acts to guide human exploration. In turn, the success of these nascent creative acts must have contributed to selective adaptation, and shaped the human brain if we inherit these complex structures today.

There are a number of reasons to suggest that multiple cortical areas and multiple physiological structures within the brain are employed during creative cognition. Indeed, human evolution would suggest *and favor* the redundancy of critical cortical operations being duplicated in the existing cortical structures. Thus, different types of mental processes, functioning through different cortical structures that interconnect the horizontal and vertical architecture of the human brain, each appear to help create the conditions for creative insight and discovery.

The Geneplore model of creative cognition (Finke, et. a., 1992) is based upon generative and explorative mental processes. These cognitive processes require both inductive and deductive strategies to discern the preinventive or emergent structures that constitute creativity. Additionally, creative cognition

appears to require the complex operations of mental synthesis, transformation, reduction, interpretation and inference, in order to generate and explore novel attributes or characteristics of the problem stimulus.Thus the Geneplore model appears to reflect both the hierarchical, as well as lateral, interconnection of various cortical functions (Fodor, 1983).

The Modular Brain and Problem Solving

Creative cognition appears to require that planning, foresight, reasoning and reflection, as well as the processes of mental synthesis, transformation, reduction, interpretation, and inference, be active in both hemispheres of the brain (both spatial/holistic and verbal/analytic processing) during cognitive problem solving. This is not a barrier since the cerebral cortex is apparently organized around neurological structures that not only support lateral cortical functions (localized areas of specialization), but also upon "deep" neurological architectures that contribute an emotional dimension to higher cortical activity. Some of these cognitive functions are fixed and rigid, while others are flexible. Some cognitive operations are innate, while others are learned.

Higher cortical structures. The separate lobes of each brain hemisphere play several important functions in creative cognition. The temporal lobes are responsible for different dimensions of cognitive memory and the perceptions of cognitive events. The occipital lobes are dedicated almost entirely to processing vision. The parietal lobes appear to "assemble" our cognitive world, putting words and images together, while the frontal lobes are generally connected with planning and foresight. If a stimulus problem is presented to a subject visually, the occipital lobe becomes involved with pattern recognition. If that stimuli is constructed from memory, the temporal lobe probably provides the source of "imagined interaction" regarding the visual components of the problem stimulus. If the creative task is the retrieval of existing structures and the formation of associations from memory, then both frontal lobes exchange information with the parietal lobes as the sequencing of mental representations require cognitive planning, and the assembly words and images takes place.

For example, in the generative act of forming associations between objects, we might start with the creative task of identifying alternative uses for a hammer. In the sequencing of cognitive events designed to approach this task, the origin of problem solving strategy might be planned in the frontal lobes, move to the temporal lobes to retrieve the sound of the word "hammer", find a pictorial

mental representation for image of a hammer in the occipital lobe, and transport these images to the parietal lobe for confirmation as the retrieved sound and image are processed. The frontal lobes might determine that association is a viable strategy to define the preinventive structure of "hammer-like attributes." The use of category exemplars (classifications of types of hammers) might again originate in the frontal lobes (both left and right) as the image of a hammer, and the concept of "pounding" are again cross-referenced in the parietal lobe. Through divergence, these two associations may lead to the memory of tack hammers, the heels of shoes, or rocks (as a conceptual dimension of pounding or striking) in the temporal and parietal lobes. Longer handles and the concept of leverage may lead to the category of sledge hammers. Shorter handles may lead to the category of hammers that have no handles such as jackhammers and pile drivers. In this fashion, these concepts move back and forth between the frontal lobes, the temporal lobes, and the parietal lobes for further refinement and analysis. By passing information back and forth between these areas, the cerebral cortex recreates from the electrical impulses that transmit messages back and forth, information such as size, shape, spatial arrangement, color and accompanying sounds connected with these mental representations. In this fashion, we gradually assemble the preinventive structures that lead to the mental representations (associations) that we want to analyze. The role of the occipital lobes may deal with feature detection and other key elements associated with these visual associations. However, these are only the lateral structures of the cerebral cortex that are responsible for modular processes.

Deep structures. The deep structures of the human brain reveal the brain's vertical architecture. These systems include the cerebrum, which lies beneath the cerebral cortex and routes information laterally between the brain hemispheres, via the corpus callosum, and the limbic system, which is directly beneath the cerebrum and is connected to the cerebral cortex by dense nerve fibers that move information from the"top-down", or from the "bottom-up" in the brain's structure.

The limbic system plays an important key role in storing memories of our life experiences. However, these memories are in the form of stored perceptual experiences or sensations, which provide for us the same kind of knowledge that mammals learn from their environments, based upon their sensory inputs.

The emotional connotations connected with this type of meaning are structured in the hypothalamus, which is located in the limbic system. But it is the function of the thalamus that has greatest concern for higher cortical functions. The thalamus helps to initiate consciousness and make preliminary classification of external events that are then routed, through the cerebrum, to various portions of the cerebral cortex.

It should be emphasized at this point that no one knows exactly what memory is, or exactly where it occurs. Memory clearly has some redundant functions in the human brain which enable us to survive certain types of neurological losses. Neurophysiologists have only begun to isolate where the processes of memory occur by examining people who have lost normal brain function due to medical inflictions, surgery to alleviate strokes or other brain complications, or some form of physical trauma that has reduced or eliminated selective aspects of cortical function. It is through the examination of groups of these patients that gradual knowledge is acquired about the normal brain by observing the dysfunctional or incomplete brain in operation. By analyzing which functions were lost when the physiology was altered, neurophysiologists can extrapolate basic information regarding the structure and function of portions of the brain. This is the basis for our knowledge regarding brain modularity and memory. In this sense, it is easy to see why brain researchers are so slow in generating important knowledge.

Creativity and modularity. Brain modularity appears to contribute to the process of creative cognition in a number of ways. Imagine for a moment that each of the creative components that have been identified in the Geneplore Model (generative processes, preinventive structures, preinventive properties, exploratory processes, and problem structures), rely upon the modules of the brain, and functions to write its contribution to the creative puzzle on a single transparent plate of glass. Each one of these etched sheets of glass would then represent the contributions of that creative process. When the plates of glass were sandwiched together and viewed from above, the collective contribution of each component would then be revealed as a grand mosaic that existed on many different planes. In order to bring the solution to the problem into clearer focus (when viewed from above), the different levels, represented by each singular sheet of glass, could be manipulated to bring that small portion of the grand design into greater coherence with the combined representation. Now imagine that there are three separate tiers of combined glass sheets that

resemble a 3-dimensional game of chess or tic-tac-toe. In order to "read" the entire "board", you have to again look down on it from above. But again each set of transparent glass panes can reconfigure its input within each different tier of the structure. Now each one of the tiers reveals a smaller portion of the grand design, but the grand design still makes sense when observed from above.

Creative cognition (as represented by the component parts of the Geneplore Model) and brain modularity (as represented by both the numerous "lateral" inputs within each tier of the structure, and the hierarchical structure of the three separate tiers), seem to work together in this fashion. The lower leveled tier has few sheets of glass, and contributes only basic information to the three-dimensional puzzle. By comparison, the upper level tier has many sheets of glass and contributes a great deal of segmented information to the puzzle. Yet none of this can be appreciated until the entire image is assembled from above. Problem solving is analogous to looking down through the physical structure of the problem stimulus, and manipulating the input from the various modules and mental representations to discern a pattern that is a potential solution. If no pattern emerges, you regenerate and reexplore the component parts until something appears as a solution.

Dreams and brain modularity. During the conscious process that we define as creative cognition, we control the focus of the mind's activities. The concept of vigilance, or attention, enables us to concentrate on a task or to direct our problem solving capacities toward a problem stimulus. Sometimes we can involve ourselves with tasks that become so repetitive that we handle conscious actions, like driving a car, on "auto-pilot." In other types of cognitive activities, we can lose our temporal bearings and focus on some functions so completely that we are not "consciously aware" of other activities that occur around us. This notion of consciousness becomes rather slippery when examining the creative process.

Because the functions of the mind never cease, an "open" type of system is apparently employed while the conscious mind lays idle during sleep. With the mind free to associate without conscious control, creativity may be the process of rampant, unguided connections that occur during sleep. Many deep right hemisphere processing (drawing, painting, spatial holistic processes) have been described as similar to sleep states: hypnotic and restful. This seems to suggest that a great deal of the mind is free to interconnect in unrestricted fashion during these processes. This subconscious processing is the ability of

the modules of the brain to freely associate rather than for the brain to be governed by conscious patterns of activity.

Creativity and Neurological Pathways

Although we have addressed creativity as the relationship that exists within and between the structures of the modular brain, creativity may also exist in the structures of the neurological pathways or networks that tie the operation of the brain together.

Nerve cells have a nucleus of different varieties and two main types of fibers: axions, which send information from one cell to another, and dendrites, which receive impulses from other cells. The type and size of the axion largely determines the flow of the neurological pulse. The size and the strength of the synaptic pulse appears to propel the signal along habitual routes between nerve cells. In the brain, there are many different types of nerve cells called neurons. The main job of each of the billions of neurons in the brain is to process the electrical codes that travel through the massive structure of the billions of cells, that each single cell is "in touch with". Yet because the brain is a living organ, these interconnections among neurons can change. Dendrites have the potential to reattach themselves to different cites on neighboring cells, which means our neurons are continually "re-wiring" themselves, altering their relationships to other neurons in the vicinity, and creating new connections within the labyrinth of pathways within the brain. These novel connections literally represent a new organization of "knowledge" within the brain.

Does creativity exist in the structure of our neurological pathways? Neural "engrams" are habitual connections of neurons through which information is transmitted around the brain. These engrams literally represent "structured thinking," or the inability to deviate from known connections. Apparently these pathways are so economical, in terms of their repeated use, that it does not take a large amount of electrical "energy" to push information from one end of the pathway to the other. This suggests that in the routinization of a neurological message along a neural engram, paths of "least electrical resistance" are frequently chosen for the journey. There appears to be little that is conscious about this process. This information has been "stored" in the habitual structure of the cortex,and in the structure of the neurological pathways.

Is creativity the divergence from habitual patterns in neuro-networks? The processes of inhibition and disinhibition in the human nervous system would

certainly support this potential. When a subject is at rest or dreaming, does the electrical circuitry of the brain change, as Alpha wave suppression seems to suggest? Perhaps this is why free association seems to take place while we are at rest (a different level or different kinds of electrical stimulation) as opposed to the connections that are made when we are focusing ourselves on a task? How can we encourage this exploration of different pathways that literally results in "new connections" within the mind?

Creativity and Neurological Transmission

The transmission of information between brain neurons is established through a process known as the synaptic connection. Dendrites are the "root-like" structures that grow away from the nucleus of the neuron. The dendrites gather information by receiving output from other neurons that they are in contact with. These contacts are functional connections to adjacent neurons across a contact point called the synapse. Actually, the dendritic contact points, called synaptic buttons, never fully touch the neurons to which they are "attached", but pass a flood of electrically charged chemicals called "neuro-transmitters" across the synaptic space that separates the synaptic button from the dendrite wall. The flood of neurotransmitters to the target site upsets the electrical balance in the dendrite as ions pass through the membrane wall of the "target neuron". This imbalance produces an electrical surge within the target cell, which in turn (if the neurotransmitters are sufficient in strength) can initiate an action potential that travels to the nucleus of the cell, and down the axion to more synaptic buttons which excite the next neuron to fire, and the process repeats itself over and over again.

This flooding of neurotransmitters will depend upon the strength of the impulse traveling down the axion, and how frequently that impulse dispatches the neurochemicals to the synapse. The neurotransmitters that flood across the synaptic space will depend upon strength of the charge, and the condition that exists on the receptor sites. Some receptor sites may be blocked by other chemicals (inhibitors), while others sites can be receptive to only certain neurotransmitters. If some of these receptor sites are blocked, the action potential may be weaken as it travels from one neuron to the next. A weak action potential may not have sufficient strength to release adequate neuro-transmitters, and may lose its strength rapidly.

Perhaps it is in this fashion that neurotransmission has a great deal to do with dictating the processes that we call creativity. During low level electrical performance, are different sets of neurotransmitters released? Do these neurochemicals cause a different type of imbalance, or bridge the synapse in such a way that the weaker action potentials, that normally dissipate quickly, range further under lower levels of electrochemical activity, disrupt the normal neural engrams and spread outward, creating a different destination than the one that is normally arrived at? Could this novel connection be creativity?

If we can inhibit or disinhibit the flow of neurochemicals across the synaptic space, would this not encourage or discourage connections? Are certain receptor sites dependent upon the chemicals within the brain? Are certain chemicals more abundant in some people than in others? And since hundreds of thousands of connections are literally necessary to move information from one structure of the brain to another, and since information may move back and forth dozens of times as creative processes unfold, is there not something in this process that suggests that creativity is electrochemical in nature?

Are there combinations of neurotransmitters that disinhibit creativity: wild cards that, when placed in combination, produce a synergistic effect that spreads synaptic impulses in various "unpredictable directions"? When we say that we are tired, after a round of brain storming with collegaues, and that our "creative juices" are "literally spent", we seem to be suggesting that we must give creative processes a rest so that neurotransmitters must be replenished from the nucleus of the cell where the vesicles are manufactured. Periods of "creativity" may occur when certain chemicals are abundant in the brain and can optimize this lateral dissemination within the brain. Creative "dry spells" may be a lack of chemical neurotransmitters, or even an inhibition at the receptor sites within the synapse. These possibilities may exist.

Conclusion

Without reservation, the opinions offered in the second half of this paper are speculative in nature. Very little is known about the processes of creative cognition, but very little is known about the structure of human memory as well. What we do seem to understand is the immense task at hand in trying to unravel the cortical structure and function of the human brain.

This paper has attempted to illustrate the potential for a scholarly approach to creative cognitive, and to suggest that based upon such a complex model, there may be multiple physiological levels at which creative cognition occurs. The generative and explorative functions of creative cognition seem to embrace such a wide variety of cognitive tasks, that the potential for creativity to exist as a unified (or fragmentized) process throughout the entire structure of the human brain, is rather high. This suggests that creativity may exist at all of the levels that have been described in the last few pages. As opposed to a singular view of the creative act, the aggregate model of creative function and structure may have more support than any singular perspective. The previous analogy, that compared the modular approach to creativity with a three-dimensional chess-board, may have even greater utility when speculating about the combined structures of brain modularity, neurological pathways, and neurotransmission, as a synergistic answer to where creativity occurs in the brain. If these three dimensions of communication structure were superimposed on the Geneplore approach to creative cognition, we would have a complex model that would be worthy of the complexity of the creative act itself.

"All we do in life is discover what has already been built into our brains."

M.S. Gazaniga, 1992

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